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NEL REPORT 1151

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## **INTERLEAVED-PLATE ELECTRODYNAMIC TRANSDUCER**

### **Part III: Design and Performance of Model 3B**

F. R. Abbott

• Research and Development Report 1151

• 20 December 1962

U. S. NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA

• A BUREAU OF SHIPS LABORATORY

Feb 26 1963

## **THE PROBLEM**

Evolve new sonar techniques to provide high-power, low-frequency, broad-band underwater sound sources. The work reported here involved modification of an interleaved-plate electrodynamic transducer to correct design deficiencies.

## **RESULTS**

1. The interleaved-plate electrodynamic transducer was modified to prevent flexure of the driving plates and water stoppage in constricted sections. The revised version (Model 3B) is basically the same as the earlier models, except for a reduction in the total electrical resistance in each set of plates.
2. The present models of transducers and inverters have given many hours of sea operation with no serious interruptions.
3. The efficiency of about 1 per cent characteristic of the Model 3B makes it unsuitable for other than experimental applications requiring a very broad usable band width.
4. Further modifications are outlined, or already in progress, to extend the usefulness of this transducer.

## **RECOMMENDATIONS**

1. Consider the Model 3B transducer suitable for use as a broad-band sonic source in a variety of sonar experiments.

2. Continue development of the interleaved-plate electrodynamic transducer, modifying it as proposed in the report, to extend its usefulness.

## **ADMINISTRATIVE INFORMATION**

Work was performed under AS 02101, SF 001 03 04, Task 8051 (NEL L3-2) by members of the Electrodynamics and Engineering Design Divisions, between September 1960 and October 1962. The report was approved for publication 20 December 1962.

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# INTRODUCTION

An interleaved-plate electrodynamic transducer was designed as a broadband underwater sound source capable of delivering an acoustic output of 250 watts from an ac input power of 100 kilowatts. The original model and an improved version (Model 3) are described in earlier reports.<sup>1,2</sup> The driving components of these models consisted of parallel plates of copper or aluminum windings separated by silicon iron strips. When sustained high-level operation of the transducers produced evidence of flexure of the driving plates, design modification was undertaken to correct this fault. In the transducer described here (Model 3B) the thickness of the plates was increased from  $\frac{1}{2}$  inch to nearly 1 inch. Also, the tubing size was increased from  $\frac{3}{8}$  to  $\frac{5}{8}$  inch O. D. to prevent water stoppage in constricted sections. Design details and operating characteristics of Model 3B are briefly described in the following sections. Details of the fabrication technique are given in an NEL Technical Memorandum.<sup>3</sup>

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<sup>1</sup>Navy Electronics Laboratory Report 883, Interleaved-Plate Electrodynamic Transducer. Part I: Static Thrust Analysis by Burwell Goode, 11 December 1958

<sup>2</sup>Navy Electronics Laboratory Report 995, Interleaved-Plate Electrodynamic Transducer. Part II: Design and Performance Analysis of Model 3 by F. R. Abbott, 11 October 1960

<sup>3</sup>Navy Electronics Laboratory Technical Memorandum 532, Evolution of a Water Cooled Wave Winding for a Reciprocating Motion Linear Drive Electric Motor, by C. Stuart and F. R. Abbott, 23 March 1962 (an informal document intended primarily for use within the Laboratory)

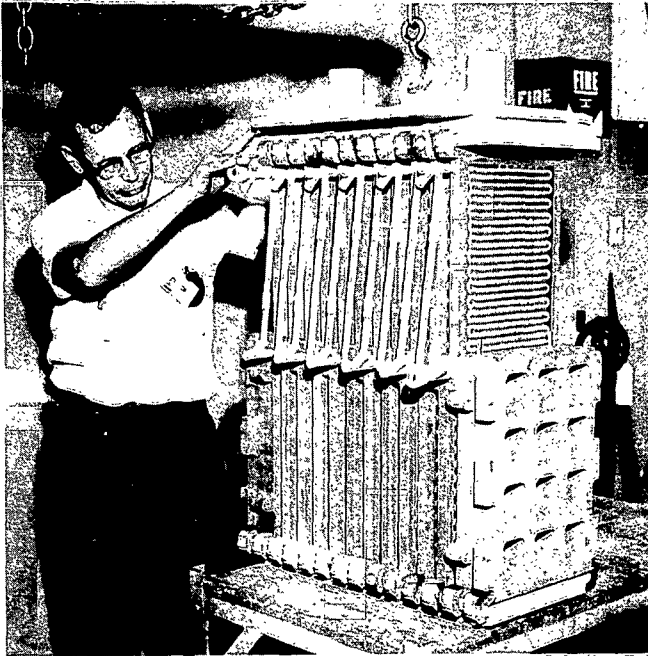
## MODEL 3B DESIGN

In design and operation the Model 3B transducer is basically the same as the Model 3,<sup>2</sup> the principal modifications being the increase in plate thickness to nearly 1 inch, and the increase in tubing size from 3/8 to 5/8 inch O.D. The nominal design acoustic output and electrical input remain the same, as does the principal operational frequency band of 15 to 600 c/s. The design changes produced a reduction in the electrical resistance of each set of plates.

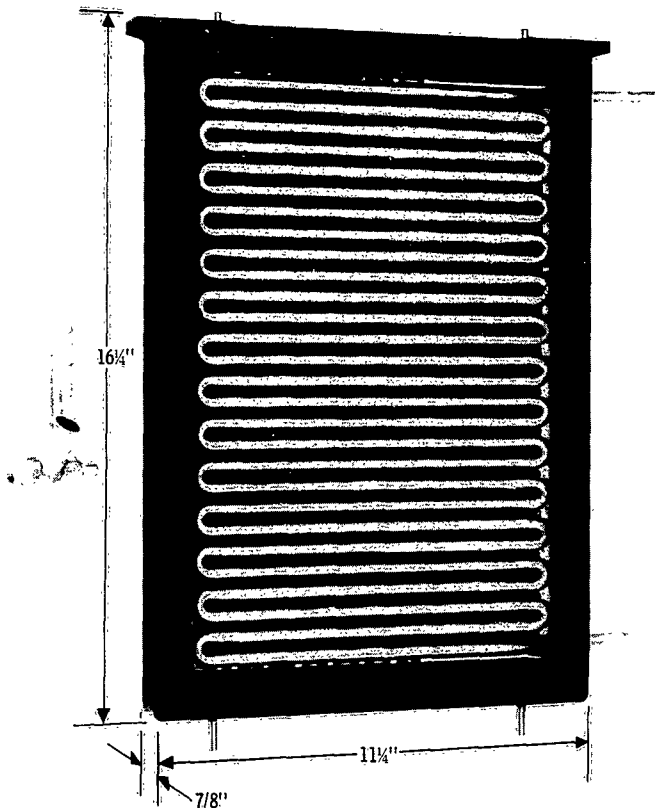
## PHYSICAL DESCRIPTION

The physical dimensions of the Model 3B transducer are as follows:

Weight	1200 pounds
Height	7 feet
Width	3 feet
Length	5 feet
Volume of coolant distilled water	7 gallons
Maximum amplitude of motion of one dome from normal centered position	1/8 inch

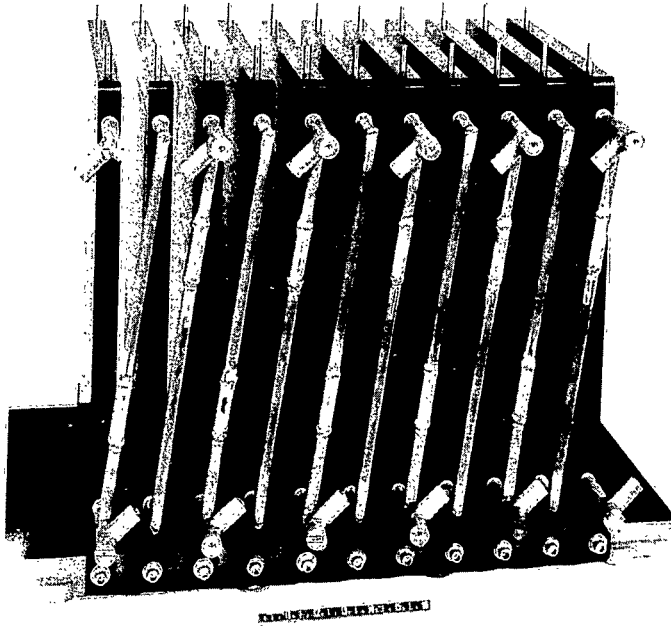


*The transducer drive unit is made up of twelve male and twelve female plates. Here the male plates are being lowered into the female set.*

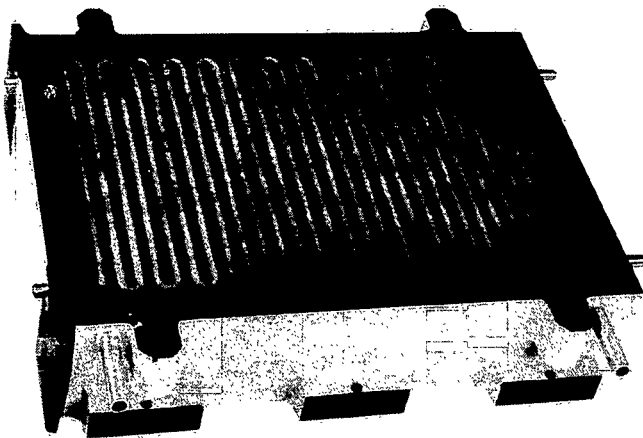


*Each driving plate uses serpentine conductor tubing formed from high-purity round aluminum tubing, 5/8 inch O. D. by 0.075 inch wall, deformed to 3/8 inch by 3/4 inch. A stack of nine 0.012-inch silicon iron strips, 0.975 inch wide, is inserted between runs of the aluminum tubing, with suitable insulation. The assembly is potted in the aluminum frame with epoxy resin. Guide pins at top and bottom assure uniform spacing. Angular fittings (as shown at left) are joined to the tubes emerging from the side to provide electrical connection with other plates of a set, and also to permit coolant water to enter or emerge from a plate.*

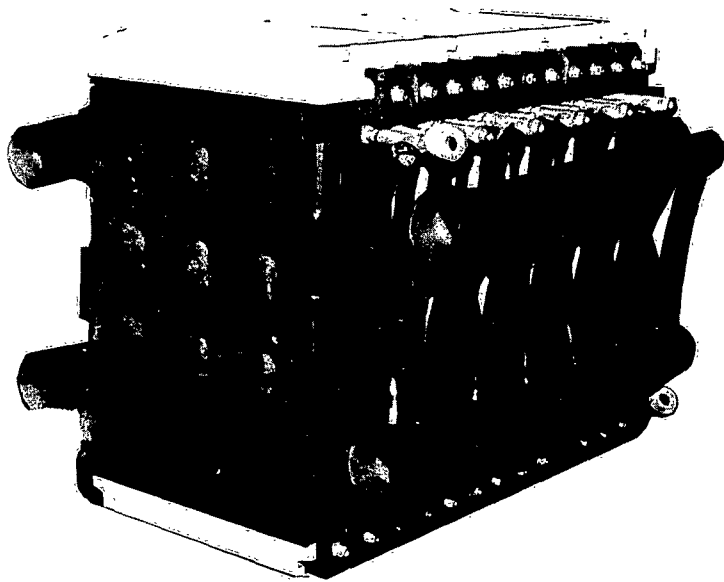




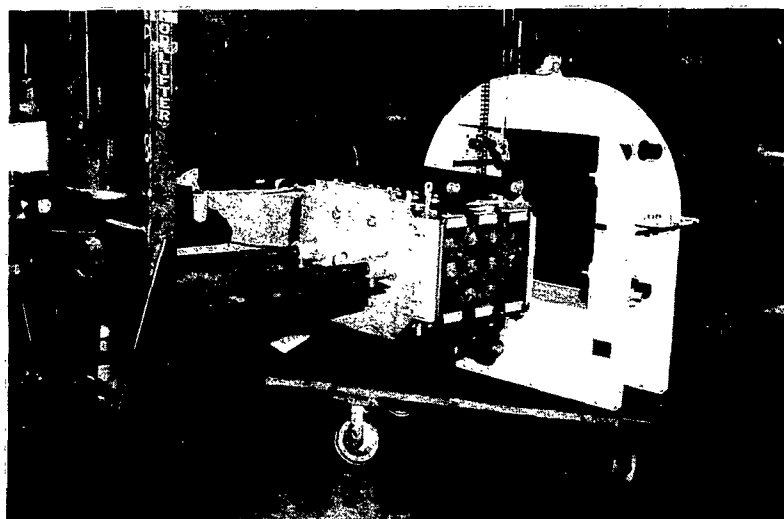
*The male plates are held to the cast magnesium header by "U" clamps which facilitate replacement of a defective plate with minimum disturbance of the set. Tubing nipples on angular electrical connections permit parallel water flow through the set.*



*Heavy construction of end plates in female set is required to provide rigidity, as the end plates are not in equilibrium with respect to transverse magnetic fields and are subject to intense mutually central attraction.*



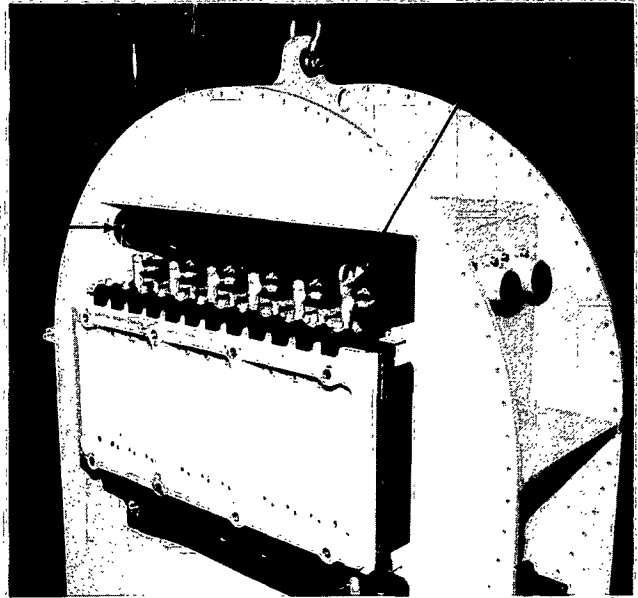
*Plastic water manifolds are connected to the assembled drive unit.*



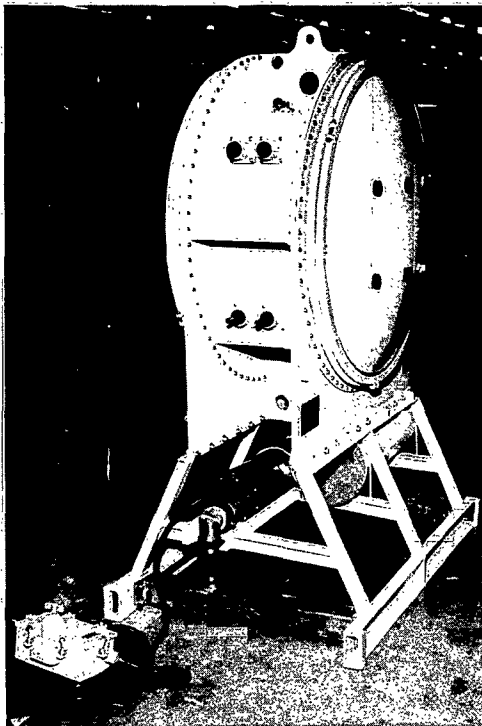
*Next, the drive unit is placed in its housing to rest on side rails. Teflon bearing strips slide on the lubricated rails to minimize friction.*

ELECTRICAL LUG

OUTLET - INLET  
TUBES



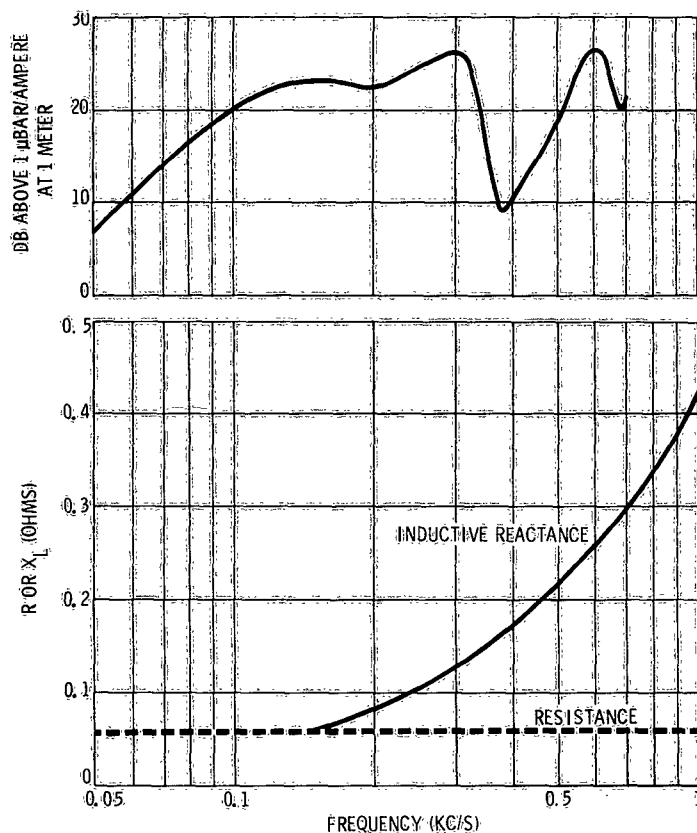
*When the drive unit is in its housing, manifolds are clamped to outlet and inlet tubes. An electrical connection lug at the top is yet to be connected to one of the waterproof Joy connectors protruding from the right side.*



*Here the completed transducer unit is viewed at the electrical feed end. Stainless steel bellows are used between the housing and the round magnesium domes. The final seal is made with the three sector clamping rings.*

## OPERATING CHARACTERISTICS

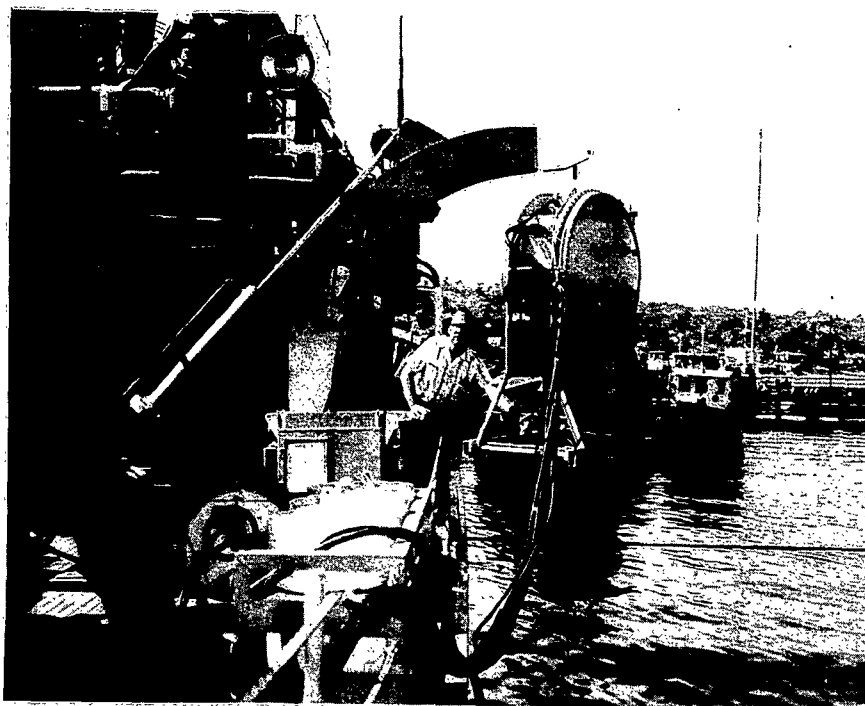
The principal operational frequency band is 15 to 600 c/s; for full power the band is about 25 to 300 c/s. The short pulse acoustic source level is 95 db re 1 dyne at 1 meter. Typical long-pulse operation is at 1200 amperes RMS and about 72 volts each, ac and dc.



*Transmitting response of interleaved-grid transducer (Model 3B) measured at Pend Oreille Calibration Station 11/9/62. Test conditions: temperature, 11.1°C; depth, 22.1 meters; current, 210 to 300 amperes input to end of cable supplied with unit;  $I_{dc}$ , 600 amperes. The pronounced anti-resonance and reduced output evident near 400 c/s are under analysis at this time.*

Internal resistance of the male plate set is 0.028 ohm and of the female plate set, 0.031 ohm.

Operation is normally at 150 to 300 foot depth. An air line with automatic electrical control compensates for external static pressure and maintains the plates at a relative position for maximum electromagnetic thrust.



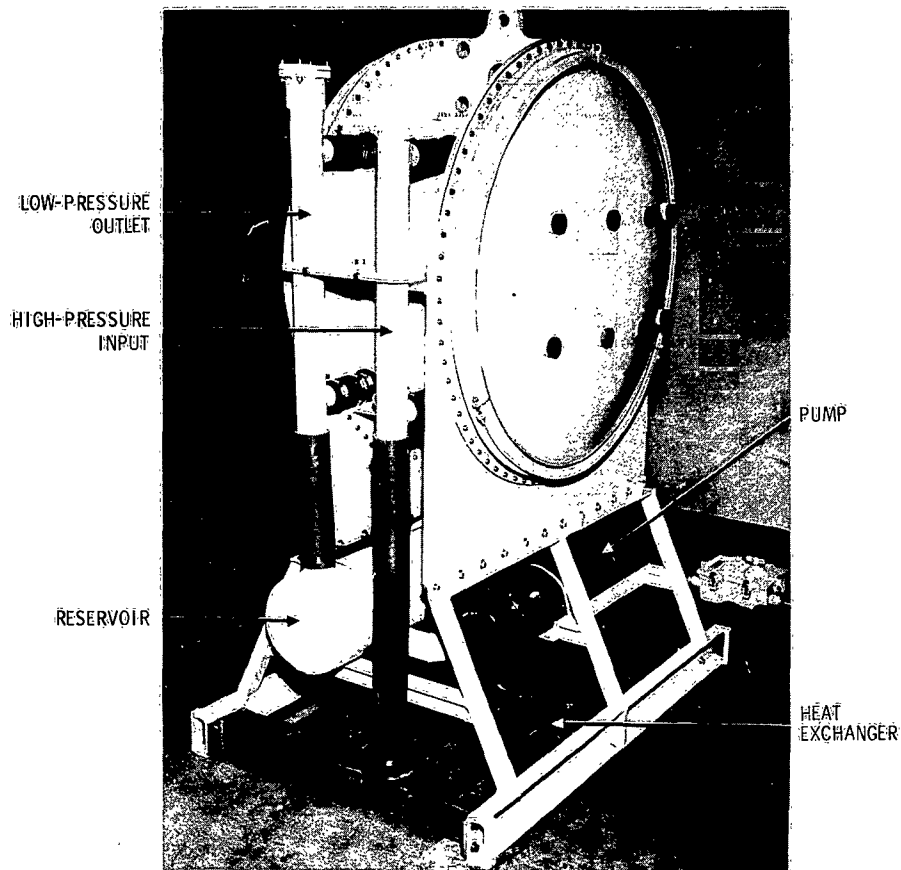
*Here the transducer unit is being lowered from USS COVE (MSI-1) to 150-foot depth, for tests. The four 300,000 cir mil electrical power leads are required to limit transmission loss.*



*The method of mounting the Model 3 units, as they are shown here aboard USS CAPITAINE, facilitates minor repairs at sea.*



*Pair of Model 3 units mounted on a submarine deck. The tractor inner tubes connected to the pressure compensation system serve as reflectors and provide about 2 db front-to-back ratio of the acoustic field.*

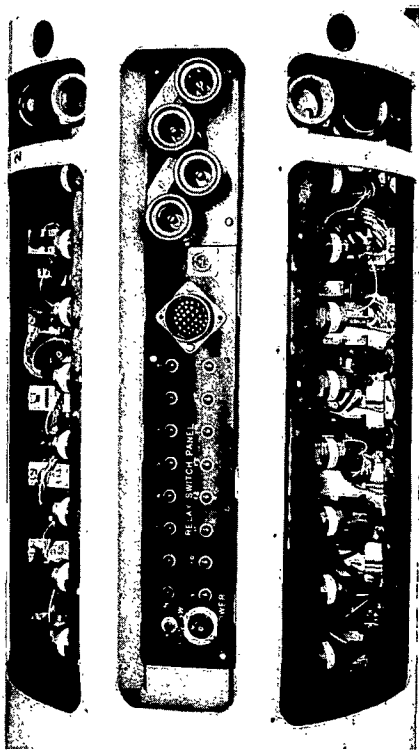


*A cooling water flow of 40 gallons per minute at 20 psi pressure is provided by 1-kw power into a submersible pump.*

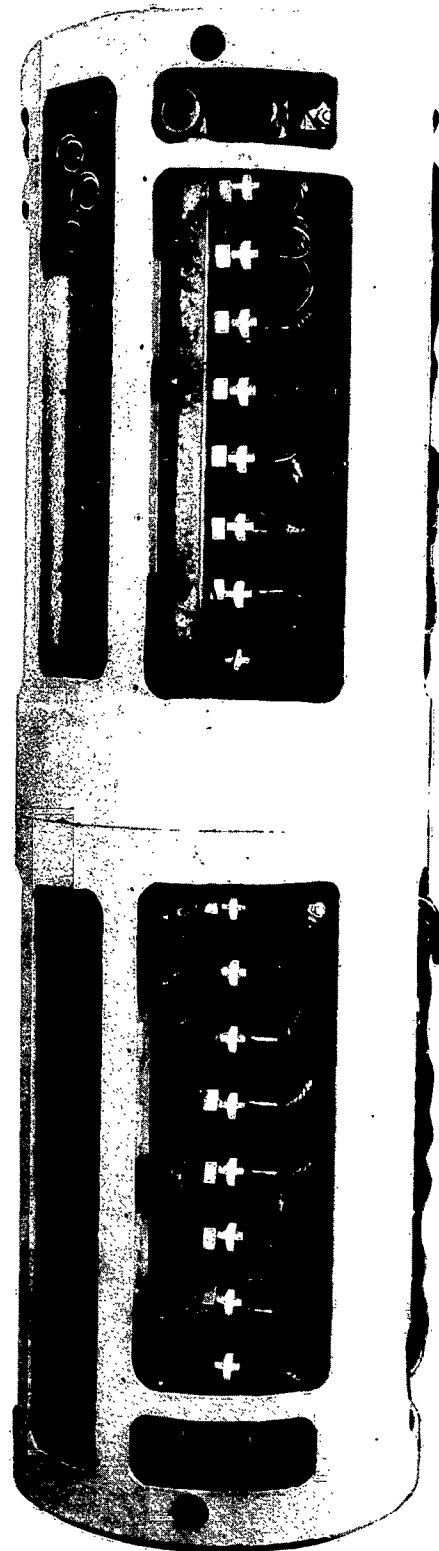
Conversion to ac at the frequency desired in operation is accomplished by semiconductor parallel inverters which are rated at hundreds of kilowatts and occupy only about 10 cubic feet.\* These inverters have been found quite reliable; the difficulty which might be associated with parallel balanced operation has been largely overcome by the increased rating of the silicon controlled rectifiers (SCR's)

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\*Circuitry for this type of inverter is published in General Electric or Westinghouse SCR manuals.



*Semiconductor parallel inverters are used to convert to ac at the frequency desired in operation. The silicon-controlled rectifiers used in the inverter are Westinghouse 200-ampere, 500-volt elements in balanced parallel groups of eight to permit 3200-ampere continuous-duty operation if desired. Space required to contain these inverters is about 10 cubic feet.*





used in them. The SCR's are Westinghouse 200-ampere, 500-volt elements in balanced parallel groups of eight to permit 3200-ampere continuous-duty operation if desired.

Damage to the costly SCR's is usually avoided by placing an instantaneous magnetic overload relay in the lead to each. Actuation of any relay opens contactors to the main dc power source. Loss of SCR's has been negligible since this protective means was introduced.

High power operation is generally pulsed, so the average power consumption is about 10 kw. Leads must be large to avoid serious power loss. The high electric current input sounds alarming but is no severe problem on shipboard. Ice breakers, nuclear submarines, and many other ship classes have high-capacity, three-phase, 480-volt sources aboard. This is transformed down to 120 volts or less and currently fed directly to SCR inverters in each phase.

## **FURTHER DESIGN CHANGES**

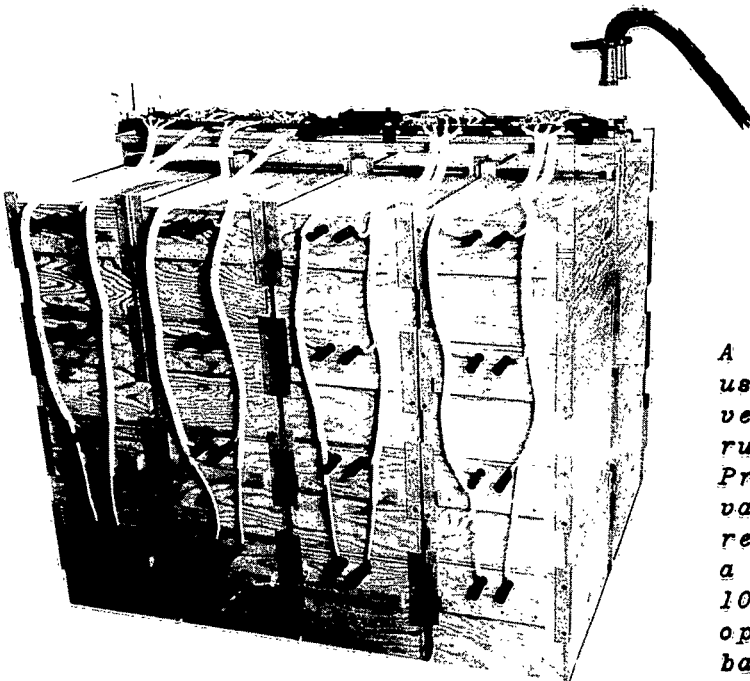
To increase the usefulness and reliability of the Model 3B, further modifications are proposed, or already under way, as follows.

The large excursion feature exploited with this device at low frequencies cannot be realized above 300 c/s because of the mass reactance of plates and the liquid media. Introduction of stiff position-restoring springs to permit resonant operation could raise the practical maximum usable frequency.

Several units are being converted to resonate at or below 200 c/s. Such resonance precludes operation at lower frequencies, but may improve performance, by several db, in a band near resonance.

The simple stack of silicon iron sheets between tubing runs in the drive plates will be replaced by sets of stampings to reduce the reluctance of the air gap and thus reduce input current requirements. This change is expected to quadruple the efficiency of the transducer and may add about 10 per cent to the cost of assembly of the driving plates. The first of these modified transducers will probably be in operation by the summer of 1963.

An inverter now being assembled will employ eight 400-ampere, 500-volt SCR's and occupy 5 cubic feet instead of the 10 cubic feet required by the present inverter unit. Its nominal pulse power rating will be 2000 amperes at 100 volts RMS. The space requirement is increased by the large ac capacitor which must parallel the load.



*A bank of ac capacitors is used with the inverters. Conventional paper-type, motor-running capacitors are used. Provision is made for plug-in variation from about 10,000  $\mu$ f required below 50 c/s down to a few hundred  $\mu$ f required at 1000 c/s. Usually stable operation over about an octave band is possible with constant capacitance.*

## **CONCLUSIONS**

1. The present models of transducers and inverters have given many hours of sea operation with no serious interruptions. Shutdown time for trouble-shooting is not severe. The transducers are reasonably resistant to accidents, but the acoustic output is sensitive to poor pressure compensation and can be reduced several db by an excess or deficiency of about 1 psi.

2. The efficiency of about 1 per cent characteristic of the Model 3B transducer makes it unsuitable for other than experimental applications demanding very broad usable band width.

## **RECOMMENDATIONS**

1. Consider the Model 3B transducer suitable for use as a broad-band sonic source in a variety of sonar experiments.

2. Continue development of the interleaved-plate electrodynamic transducer, modifying it as proposed, to extend its usefulness.

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